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Bertoli, S ; Bodmer, D ; Probst, R

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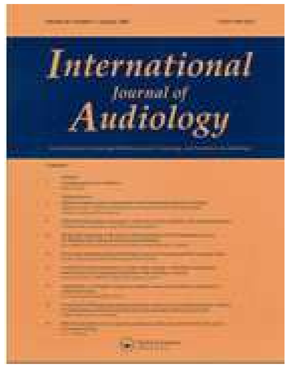
DOI: https://doi.org/10.3109/14992020903473431



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Journal:	*International Journal of Audiology*
Manuscript ID:	TIJA-2009-01-0008.R3
Manuscript Type:	Original Paper
Date Submitted by the Author:	
Complete List of Authors:	Bertoli, Sibylle; University Hospital, Otorhinolaryngology Bodmer, Daniel; University Hospital, Otorhinolaryngology Probst, Rudolf; University Hospital, Otorhinolaryngology
Keywords:	Hearing Aid Satisfaction, Hearing Aids, Demographics/Epidemiology, Instrumentation

Survey on hearing aid outcome in Switzerland: Associations with type of fitting (bilateral/unilateral), level of hearing aid signal processing and hearing loss

Authors:

Sibylle Bertoli[a], Daniel Bodmer[a], Rudolf Probst[b]

Affiliations:

[a] Department of Otorhinolaryngology, University Hospital Basel, Switzerland

[b] Department of Otorhinolaryngology, University Hospital Zurich, Switzerland

Keywords: Bilateral; hearing aids; hearing aid use; satisfaction; signal processing; survey; unilateral

Corresponding author:

Sibylle Bertoli

Department of Otorhinolaryngology

University Hospital

Petersgraben 4

CH-4031 Basel

Switzerland

Tel: +41 61 265 2042

Fax: +41 61 265 3883

E-mail: sbertoli@uhbs.ch

Abstract

The present investigation further analyzed results of a previously reported survey with a large sample of hearing aid owners (Bertoli et al, 2009) to determine the individual and technological factors related to hearing aid outcome. In particular the associations of hearing loss, level of signal processing, and fitting type (bilateral versus unilateral fitting) with hearing aid use, satisfaction with and management of the aid were evaluated. A sub-group with symmetrical hearing loss was analyzed (n=6027). Regular use was more frequent in bilateral users and in owners of devices with more complex signal processing, but the strongest determinant of regular use was severity of hearing loss. Satisfaction was higher in the group wearing simple devices, while fitting type and degree of hearing loss had no influence on satisfaction rates. Moderate and severe hearing loss was associated more frequently with poor management of the aid than mild hearing loss. It was concluded that bilateral amplification and advanced signal processing features may contribute to successful hearing aid fitting, but the resulting differences must be considered to be relatively small.

Introduction

In 2005, we conducted a national representative cross-sectional survey with the aim to evaluate the quality and efficiency of the Swiss hearing aid dispensing system. The two main outcome variables were hearing aid use and satisfaction with the aid(s). The rationale of this survey is briefly summarized: Switzerland has a hearing aid provision system that differs in three main aspects from the systems in other countries. First, to determine candidacy for a hearing aid, not only audiometric criteria (i.e., degree of hearing loss), but also the amount of social and emotional handicap caused by the hearing loss are used. Second, there is a close collaboration between Ear, Nose, and Throat (ENT) practitioners and hearing aid dispensers. While the ENT physician evaluates the need for a hearing aid and determines the type of fitting, devices are provided by private hearing aid dispensers. Their service includes comparative fitting and trial of different types of devices, as well as continuous counseling after the fitting. Finally, there is generous financial support from the social security system (disability or retirement insurances, depending on the age of the candidate). These insurances pay either all or a substantial portion of the total cost of the amplification including a fixed overall compensation to the hearing aid dispenser for services rendered. For persons who are still working, bilateral fitting is covered. Persons who have retired must pay for the second aid if desired and only 75% of the costs of the first aid are reimbursed.

The main results of the survey pertaining to all respondents have been published elsewhere (Bertoli et al, 2009). Rates of regular use (85%) and satisfaction with the aids (80%) were found to be high compared to data from other countries. Various factors influencing the outcome of hearing aid provision were identified including age, gender, regional language, total duration of use, fitting type, hearing aid category and hearing loss. The purpose of the current report was to investigate in greater detail associations of fitting type (bilateral vs. unilateral), level of signal processing (complex vs. simple) and hearing loss with hearing aid use, satisfaction with and ability to manage the aid in a large cross-sectional sample of hearing aid owners. Due to the increasing proportion of elderly people, there is also an increase in the number of hearing aid users, with growing expenses for health insurance companies or National Health Services of the government. In Switzerland, for example, according to an evaluation carried out by the Swiss Government, the number of persons provided with hearing aids has nearly doubled from 1995 to 2005 (Swiss Federal Audit Office, 2007). In addition, 73% of those paid for by the disability insurance were bilateral in 2005, and approximately 50% of the hearing instruments were from the most expensive of three reimbursement categories indicating more sophisticated technical features. To reduce these expenses, cost-saving measures such as cutting the financial support for the second aid or reducing the overall contribution to the aid(s), are being considered. Therefore, additional information on the potential benefit of bilateral fitting and advanced technology is needed. Having quantitative data from a large sample with a cross-sectional design may be helpful to determine the contribution of technical features and fitting type to the outcome of hearing aid fitting. Analyses were performed on a subgroup of the respondents who had a documented symmetrical hearing loss.

Bilateral versus unilateral fitting

As reviewed by Dillon (2001), there is evidence from various laboratory studies that two hearing aids are superior to one aid in most subjects with symmetric hearing loss. The possible benefits of bilateral fitting include better speech understanding (Kobler and Rosenhall, 2002; Moore et al, 1992), in particular in noisy environments (Dreschler and Boymans, 1994; Leeuw and Dreschler, 1991; Nabelek and Mason, 1981), better sound quality (Balfour and Hawkins, 1992; Erdman and Sedge, 1981), better sound localization (Byrne et al, 1992; Dreschler and Boymans, 1994; Kobler and Rosenhall, 2002; Punch et al, 1991; Stephens et al, 1991), and improved perception of distance and movement (Noble and Gatehouse, 2006). Principles of acoustics and hearing physiology also support the use of bilateral fitting. However, clinical field studies have failed to show a clear advantage of bilateral fittings (e.g., Noble and Gatehouse, 2006).

Level of hearing aid signal processing

Another controversy is related to the level of hearing aid signal processing, which has developed considerably during the past decade. The most important change has been the transition from analog to digital signal processing with its advanced possibilities, such as different processing in frequency channels, feedback management or automatic adjustment to different auditory environments. Other changes include special microphone technology. In light of the obviously higher costs of these advanced technologies, it is legitimate to question whether devices with sophisticated signal processing features are superior to simpler aids, resulting in higher user and satisfaction rates and easier management of the devices.

Numerous studies have assessed one specific type of aid or processing feature, typically in a small group of subjects (e.g., Arlinger et al, 1998; Dillon, 1996). Such device-specific studies are generally not helpful for an overall evaluation of the relationship between hearing aid technology and everyday use, because methodological differences preclude a direct comparison of results. In addition, they have not shown consistent superiority for any type of signal processing, even in more or less artificial laboratory environments.

A few studies comparing devices with analog and digital technology have indicated that digital aids were not superior to analog aids in terms of benefit, satisfaction, use and management (Parving, 2003; Parving and Sibelle, 2001; Taylor et al, 2001). In contrast, Wood and Lutman (2004) reported, based on a study with a single-blind cross-over design, that users were more likely to prefer the digital aid over the linear analog aid because of better sound quality and performance in noise. However, there were no significant differences in reported use (hours per day) and quality of life measures between the two devices.

Since the first fully digital signal processing hearing aids were launched in 1995, analog hearing aids have been almost completely replaced by digital aids making a comparison of the two technologies superfluous. Rather, the complexity of the signal processing features of the hearing aids should be considered. Some studies have investigated the relative benefit provided by different types of hearing aids (Larson et al, 2000; Hosford-Dunn and Halpern, 2001; Jerram and Purdy, 2001; Kochkin, 2003; Yueh et al, 2001). For example, Larson et al (2000), in a study with a cross-over design (i.e., each patient wore each of the three aids for the same duration), compared three commonly used hearing aid circuits (linear peak clipper=PC; compression limiter=CL; wide dynamic range compressor=WDRC). Efficacy was measured using tests of speech understanding, sound quality, and patient rank-order ratings. Some test results suggested that CL and WDRC provided a significantly better listening experience than PC in word recognition, loudness, overall preference, aversiveness of environmental sounds and distortion. In the rank-order ratings, patients preferred the CL (41.6%) more frequently than the WDRC (29.8%) and PC (28.6%). Differences between the three circuits were small and the authors concluded that cost versus benefit considerations should be taken into account. In another randomized controlled trial, the effectiveness of a nonprogrammable nondirectional microphone hearing aid, a programmable directional microphone hearing aid, and an assistive listening device were compared against the absence of amplification (Yueh et al, 2001). Programmable hearing aids with a directional microphone had the highest level of effectiveness (mean improvement in the Hearing Handicap Inventory for the Elderly (HHIE) for a conventional device was 17.4 points, and 31.1 points for the programmable device). Similar trends were seen for free-text diary entries, self-reported communication ability, hearing aid use, and willingness to pay for replacement devices.

Outcome measures of successful hearing aid fitting and possible confounding factors

Subjective ratings of the respondents on hearing aid use, satisfaction and management were used to explore whether potentially cost-increasing factors, such as bilateral amplification and more advanced signal processing contribute to a successful hearing aid fitting. While hearing aid use and satisfaction are commonly accepted outcome measures (e.g., Cox et al, 2000; Dillon et al, 1999), to our knowledge management has been used only by Parving (2003) and Parving and Sibelle (2001) to compare analog vs. digital hearing aid provision. In the current study with a focus on the complexity of hearing aid signal processing, management was chosen in addition to use and satisfaction, because automatic control features such as noise rejection, feedback control, or automatic choice of algorithms according to the acoustic environment could contribute to easier management of the hearing aid.

Other potentially confounding individual variables were considered: demographic factors (age and gender), overall duration of hearing aid use, age of current aid and degree of hearing loss. Among these factors, special attention was paid to the degree of hearing loss. Since we could combine our survey data with information from the hearing aid dispensers on hearing loss, the current study provides the unique opportunity to investigate the associations between degree of hearing loss and various outcome measures in a large cross-sectional sample. Studies on hearing aid outcome with large samples are scarce and none of these has reported audiometric data on the degree of hearing loss (Kochkin, 2005; Parving & Sibelle, 2001; Parving, 2003; Smeeth et al, 2002).

Methods

Study population and Procedure

Details on the methods and the population have been reported elsewhere (Bertoli et al, 2009). Briefly, the survey was conducted in collaboration with a large hearing aid dispensing company with stores in all parts of Switzerland, a market share of 20%, and an electronic customers' data base. All customers aged 18 years or older, who had visited one of the hearing aid dispenser's offices between January 1, 2002 and April 30, 2005 were contacted.

Most demographic characteristics of the study population were not different from representative data of the Swiss Health Survey 2002 on hearing aid users (Bundesamt für Statistik, 2004), except for women aged >75 years, who were overrepresented in our sample. Thus, data from this report largely represent a national cross-sectional adult population.

A questionnaire was sent together with an explanatory letter in June 2005 to 14 285 hearing aid owners. A second mailing to the non-respondents (n=8416) followed in November 2005. The overall response rate of the study was 62% (n=8707). The current report focuses on a subgroup of the respondents with symmetrical hearing loss (n=6027). Subjects with asymmetrical hearing loss or audiometric data available for only one ear were excluded from the present analyses.

Questionnaire

A 12-item questionnaire was developed after a review of published questionnaires on hearing aid use (Cox et al., 2000, Dillon et al., 1999, Kiese-Himmel and Kruse, 2000, Kochkin, 2000, Parving, 2003, Stock et al., 1995). The questionnaire contained items about the hearing aid (age of current aid, time of first fitting, unilateral or bilateral fitting), use (days per week, hours per day, frequency of battery change), satisfaction with and management of the hearing instrument, and reasons for non-use. Bilaterally fitted respondents were also asked if they used both aids or only one. The wording of the items related to use, satisfaction and management is stated in Table 5. According to the definitions used in other studies (Parving and Sibelle, 2001; Parving 2003), regular use was defined as daily or weekly use and non-regular use as occasional or never used. To define satisfaction and dissatisfaction, the answers very satisfied/rather satisfied and rather unsatisfied/very unsatisfied were grouped, and to define good and bad management, the answers very well/rather well and rather bad/very bad were pooled. The question concerning reasons for non-regular use was answered only by those participants indicating non-regular use of their aids. Answers were predetermined and respondents were asked to tick all alternatives that applied. In addition, they could enter other reasons for non-regular use. Finally, participants were asked for consent for the researchers to access their results on hearing loss and hearing aids using information from the dispenser's database. Only results for those who provided consent were included in this research. Ninety-one percent of the respondents agreed. The study procedure and the questionnaire were approved by the Ethics Committee of Basel and Baselland (EKBB).

Data on hearing loss and hearing aids

Data on hearing loss and hearing aids were obtained from the hearing aid dispenser's electronic customers' database. The percentage of hearing loss was calculated using the definition of the Council on Physical Therapy, American Medical Association (CPT-AMA), which weights the hearing thresholds for the frequencies 0.5, 1, 2 and 4 kHz according to their importance for speech understanding (Council on Physical Therapy, 1942). The CPT-AMA definition is routinely used by the Swiss ENT practitioners to determine candidacy for a hearing aid and was therefore given preference to the more widely used pure-tone average (PTA) of the same frequencies. Using the CPT-AMA criteria, hearing loss was defined as mild (≤40%), moderate (41-60%) or severe (>60%). In case of different categories for right and left ears, the better ear determined the hearing loss category. For 6710 respondents, pure-tone data were available for both ears. Of those, 6027 had a symmetrical hearing loss, which was defined as a difference of less than 30% hearing loss (CPT-AMA) between the right and left ear. Only those respondents with symmetrical hearing loss were included in this study.

Bilateral and unilateral fittings were defined as the two categories of fitting type. Six categories of hearing aids were defined, depending on the complexity of signal processing and options. A detailed description of the categories is provided in Table 1. If for bilaterally fitted persons the two hearing aids were from different signal processing levels, the higher level determined the hearing aid category. Given the irregular frequency distribution across the six categories, categories were dichotomised as "simple" (categories 1-3) and "complex" (categories 4-6) for further analyses.

Data analysis

Data were analyzed using STATA software (version 9.2). Descriptive data on hearing aid use, satisfaction and management of the aid are presented as a function of type of fitting (bilateral/unilateral), hearing aid category (complex/simple) and amount of hearing loss (mild/moderate/severe). Group differences were assessed using Chi-square tests (for qualitative variables) and the Wilcoxon rank sum test (for quantitative and ordinal variables). Spearman's rank correlation was used to measure the strength of association between two ordinal variables. Differences were considered statistically significant for p-values <0.05.

Logistic regression models for regular hearing aid use, satisfaction with and good management of the aid were conducted to determine the relative risks of negative outcomes (i.e., non-regular use, dissatisfaction and poor management) and to investigate their relationships with amplification, hearing aid type and amount of hearing loss, taking into account possible confounding co-factors. Because all three dependent variables describe relatively rare events, the odds ratios may be interpreted as relative risks. The following independent variables were included in the model for regular use: age, gender, total duration of hearing aid use, age of current aid, fitting type, satisfaction, management, degree of hearing loss, level of signal processing (simple/complex). The model for satisfaction contained the same variables, with the exception of satisfaction, which was substituted by hearing aid use. Accordingly, the model for management contained use and satisfaction but not management as independent variables. Results are expressed as odds ratios (OR) with 95% confidence intervals (95% CI). Age, time since first fitting and hearing loss were measured continuously but used as categorical variables because of nonlinear associations with regular use. All models were also tested against the null models using the likelihood ratio test. Goodness-of-fit of the models was assessed using the Hosmer-Lemeshow test. Adjusted predicted prevalences for regular use, satisfaction and good management are provided as a function of fitting type and level of hearing aid signal processing.

Results

Respondents

Table 2 shows age and gender distribution by type of fitting and level of hearing aid signal processing. Of the 6027 respondents with symmetrical hearing loss, 69.4% (n=4182) were fitted bilaterally and 30.6% (n=1845) were fitted unilaterally. For the unilateral fittings, the right ear (57.2%; n=1055) was used more frequently than the left ear (42.8%; n=790). The mean age was 71.7 years (±11.8 years SD) for the bilaterally fitted group and 79.2 years (±9.5 years SD) for the unilaterally fitted group. The median values were 73 and 80 years, respectively. The proportion of bilateral fittings was larger in individuals aged between 18 and 69 years, ranging between 80 to 91% per decade. After 70 years, the proportion decreased continuously from decade to decade from 68% to 33% for the centenarians. These age differences between the two groups were highly significant ($p<.0001$) and may reflect the fact that bilateral fittings are covered by the social insurances in Switzerland only for persons who are still working. Of the sample, 60.6% were men. Overall, men were more frequently fitted with two aids than women (bilateral fitting: 72.2 % vs. 65.0%; $p<.0001$).

For 5973 respondents, information about the processing level of their hearing aids was available. Overall, 61.7% (n=3720) wore hearing aids with more complex signal processing features. No significant differences across age groups and by gender were observed for the level of hearing aid signal processing. The mean age was 74.1 years (±11.4 SD) in the group with complex signal processing features and 74.2 years (±12.0 SD) in the group with more simple features. The proportion of devices with complex signal processing was 62.8% in men and 61.4% in women.

Hearing loss

Figure 1 depicts the composite mean hearing thresholds of the right and left ear by fitting type and level of signal processing. Bilateral users had better thresholds compared to unilateral users throughout the whole frequency range. The mean PTA of the better ear at the frequencies 0.5, 1, 2, 4 kHz was 48.5 dB (±13.0 dB SD) in bilateral and 50.1 dB (±12.9 dB SD) in unilateral users. The mean percentage of hearing loss (CPT-AMA criteria) of the better ear was 49.5% (±19.4% SD) in the bilateral and 51.8 % (±19.4 % SD) in the unilateral users. Users of devices with complex signal processing had better hearing thresholds compared to those with more simple features for the frequency range from 0.25 to 2 kHz, but not for the higher frequencies. The mean PTA was 48.2 dB (±12.6 dB SD) for subjects with complex and 50.2 dB (±13.6 dB SD) with simple hearing aids. The mean percentage of hearing loss was 49.2 % (±19.2% SD) in the users of complex and 51.6% (±19.6% SD) in the users of simple devices.

Table 3 depicts the proportion of bilateral vs. unilateral users and users with complex vs. simple signal processing features as a function of the degree of hearing loss. Users with mild hearing loss were more likely to be fitted with two aids and with more complex devices compared to those with moderate and severe hearing loss (bilateral: 73.1% vs. 69.3% and 65.6%; p<.0001; complex: 65.2% vs. 61.8% and 59.9%; p=.0009).

Hearing aids

Table 4 depicts the age of the current aid, the overall duration of hearing aid use and the hearing aid category by fitting type and level of signal processing. Fifty-five percent owned a hearing aid that was not older than 2 years. Bilateral users were more likely than unilateral users to have their current aid purchased less than 1 year ago (24.6% vs. 18.1%; $p<.0001$). The mean overall duration of hearing aid use was 6.8 (±8.4; range 0-65) years in the bilateral group and 6.0 (±7.8; range 0-55) years in the unilateral group. The median duration was 3 years for both groups. The mean age at the time of the first hearing aid fitting was 64.7 (±13.9) years in the bilateral and 72.9 (±11.9) years in the unilateral users.

Overall, 61.7% had hearing aids from categories 4-6, i.e. those with the more advanced signal processing features The proportion of bilateral fittings was higher among owners of complex devices (65.1% vs. 54.1%; $p<.001$). Owners of devices with complex signal processing more frequently had hearing aids less than 1 year old as compared to those with simpler hearing aids (26.6% vs. 15.9%; $p<.0001$). The mean overall duration of hearing aid use was 6.1 (±7.6; range 0-55) years in the complex group and 7.2 (±9.1; range 0-65) years in the simple group. The median was 3 years in both groups. The mean age at the time of first fitting was 67.6 (±13.3) years among owners of complex devices and 66.6 (±14.6) years among those with simple devices.

Hearing aid use, satisfaction and management as a function of type of fitting

Of those subjects with bilateral hearing aids, 88.5% wore both aids regularly, 4.7% only one of the two aids, and 6.3% indicated that they alternated between bilateral and unilateral use of their aids.

Table 5 depicts the percentages of hearing aid use, satisfaction and management as a function of type of fitting (bilateral vs. unilateral). For hearing aid use measured in days per week, there was no significant difference between the two groups ($p=.0580$). Regular use (= response categories "daily", "most days" and "some days") was 88.5% among all respondents, 89.9% in bilateral and 85.3% in unilateral users. Compared to unilateral users, the bilateral users wore their aids significantly longer per day (at least 4 hours per day:

79.9% vs. 69.4%; p<.0001).

Bilateral users were more frequently very satisfied with their aids (35.4% vs. 29.9%; p<.0001) and they were reportedly more likely to handle their instrument very well compared to unilateral users (51.2 vs. 42.0%; p<.0001). In the total sample, 86.3% were either very or rather satisfied (87.2% in the bilateral and 84.2% in the unilateral group); and 91.5% were able to manage their aids either very or rather well (92.6% in the bilateral and 88.9% in the unilateral group).

Hearing aid use, satisfaction and management as a function of signal processing level

Table 6 lists the patterns of use, satisfaction and management for hearing aids with complex and simple signal processing features. Again, there was no significant difference in the pattern of responses between the two groups when use was quantified in days per week (regular use: 89.6% vs. 86.6%; p=.1147), but only when it was quantified in hours per day (at least 4 hours per day: 77.9% vs. 74.6%; p=.0108).

A higher percentage of users of complex devices reported that they were very satisfied with their aids (34.7% vs. 32.0%; p=.0397) and able to manage their aids very well (50.5% vs. 44.7%; p<0.0001) compared to the users of simple devices. When the responses were pooled, there was only a small difference between the two groups. Overall, 86.6% of those with complex devices were either very or rather satisfied compared to 87% of those with simpler devices. Very or rather good management was reported by 92.1% of the complex group compared to 90.5% of the simple group.

Hearing aid use, satisfaction and management as a function of the degree of hearing loss

Table 7 lists the percentages of hearing aid use, satisfaction and management as a function of hearing loss. Of the subjects with severe hearing loss, 82.8% wore their aids every day, compared to 57.5% with moderate and 40.5% with mild hearing loss ($p<.0001$). Subjects with severe hearing loss were more likely to wear their aids for more than 8 hours per day than those with moderate and mild hearing loss (68.5% vs. 47.5% and 37.7%, respectively; $p<.0001$).

Satisfaction was independent of hearing loss ($p=.1117$), whereas the ability to handle the hearing aid very well was more frequent among hearing aid users with mild compared to moderate and severe hearing loss (51.9% vs. 47.1% and 46.2%, respectively; $p=.0014$).

Reasons for non-regular use

Respondents who used their aids only occasionally (n=629; 10.4%) or never (n=49; 0.8%) were asked for the reasons. Table 8 provides the results. A significantly higher percentage of bilateral hearing aid owners as compared to unilateral hearing aid owners indicated the following factors as reasons for non-use: noisy situations are disturbing ($p=.013$), unpleasant side effects ($p=.011$) and poor fit and comfort ($p=.008$). Unilateral owners tended to complain more frequently about poor benefit and difficulties with management, but these differences did not reach significance ($p=.063$ and $.144$, respectively). The most commonly selected reason for non-use in both bilateral and unilateral hearing aid users was finding the use of hearing aids in noisy situations disturbing. For bilateral hearing aid users, the least selected reason was “difficulties with management”, whereas for unilateral users the least selected reason was “poor fit and comfort”. There were no significant differences between owners of complex and simple aids in the reasons indicated for non-use.

Determinants of regular hearing aid use, satisfaction and good management

The determinants of factors potentially related to regular use, satisfaction and good management were examined to identify those factors significantly associated with non-regular use, dissatisfaction and bad management. Multivariable logistic regression models were used to explore the associations of bilateral versus unilateral use, signal processing level and degree of hearing loss with regular hearing aid use, satisfaction with and good handling of the aid, while also taking into account other possibly confounding co-factors. In the models for regular use, satisfaction and good management the following variables were included: age (4 categories), gender, total duration of hearing aid use (4 categories), age of current aid (4 categories), unilateral/bilateral amplification, degree of hearing loss (3 categories), and level of hearing aid signal processing (2 categories). In addition, satisfaction (4 categories) and management (4 categories) were entered in the model for regular use, hearing aid use (5 categories) and management in the model for satisfaction, and hearing aid use and satisfaction in the model for management. Tables 9, 10 and 11 summarize the odds ratios with 95% confidence intervals of the three logistic regression analyses. All of the three outcomes considered showed the strongest association with the other two outcomes if these were included among the model covariates. This reflects the fact that all three outcomes represent closely related and complementary aspects of hearing aid fitting outcome.

Non-regular use was significantly associated with unilateral amplification (OR 1.38, 95% CI 1.12-1.71, p=.003) and with devices with simple signal processing (OR 1.25, 95% CI 1.03-1.52; p=.023), i.e. unilaterally fitted users and those with simple hearing aids were at a higher risk of non-regular use. Moderate (OR 0.5, 95% CI 0.41-0.63; p<.0001) and severe hearing loss (OR 0.19, 95% CI 0.14-0.28; p<.0001) decreased the risk of non-regular use considerably. Other factors associated with a lower risk of non-use were: female gender (OR 0.61, 95% CI 0.49-0.75; p<.0001) and total duration of hearing aid use > 5 years (OR 0.38, 95% CI 0.26-0.57; p<.0001).

The risk of not being satisfied with the hearing aid increased significantly with a total duration of use between 2 to 5 years (OR 1.49, 95% CI 1.08-2.05; p=.015) and age of current aid >2 years (OR 1.45, 95% CI 1.01-2.07; p=.041). Owners of hearing aids with simple signal processing features were less likely to be dissatisfied with their aids than those with more complex devices (OR 0.80, 95% CI 0.65-0.98;p=.035), but type of fitting (bilateral vs. unilateral) and degree of hearing loss were unrelated to dissatisfaction.

Difficulty with management of the aid was not related to any of the hearing aid characteristics (total duration of hearing aid use, age of current aid, bilateral vs. unilateral fitting and complexity of signal processing), but there was a strong association between degree of hearing loss and bad management (OR 2.37, 95% CI 1.54-3.64; p<.0001). The age of the hearing aid owners was unrelated to the ability to manage the device.

Discussion

The current study examined data from a national representative sample of hearing aid owners on outcome as measured by hearing aid use, satisfaction and management, taking into account information on the amount of hearing loss, type of fitting and hearing aid signal processing. No comparable data are available from other studies with large samples (Dillon et al, 1999; Parving and Sibelle, 2001; Parving, 2003; Smeeth et al, 2002; Stock et al, 1995). Despite the limitations of epidemiological and cross-sectional studies that cannot consider individual factors such as the patient's personality, social demands, expectations and perceived handicap, our data support some superiority of bilateral over unilateral amplification and of high-tech instruments over more simple devices, but the differences were relatively small. In comparison to these differences, degree of hearing loss was a strong determinant of successful hearing aid outcome, when measured in terms of regular use.

Bilateral vs. unilateral fitting

In our study, bilateral amplification was significantly associated with a higher rate of regular use of hearing aids. Although respondents wearing two aids reported more frequently to be very satisfied with their aids and able to handle them very well, these results were not confirmed in logistic regression analyses, where other potentially contributing factors were taken into account. In a recent survey on long-term outcome measures of bilaterally and unilaterally fitted persons matched for age, degree of hearing loss and audiometric asymmetry, the bilateral group had significantly higher self-reported benefit scores, but did not differ from the unilateral group in terms of use, residual handicap and satisfaction (Boymans et al., 2009). In this study, hearing aid use was measured in hours per day, whereas we used days per week as the main parameter. Different methods to quantify use may lead to the different results. Studies with smaller sample sizes and a cross-over design have reported subjective preference of bilateral amplification after subjects had tried both bilateral and unilateral amplification for some time (Erdman and Sedge, 1981; Stephens et al, 1991). The responses to our survey also represent subjective outcome ratings of hearing aid provision. However, the participants in our study did not try different types of fitting and therefore their judgments were not comparative. This may explain the somewhat different results compared to these studies.

Respondents who had indicated that they used their devices only occasionally or never were asked for the reasons. More persons fitted bilaterally than fitted unilaterally complained about disturbing noisy situations, unpleasant side effects (e.g., rashes, itching, pain), poor fit and discomfort. Unpleasant side effects may also be related to the style of the aid (behind-the-ear, in-the-ear, in-the-canal, or open versus closed fitting). However, this information was not obtained in our study. Kobler et al (2001) reported similar results for bilaterally fitted persons who were using only one of the two aids. Sixteen percent indicated that background sounds became too noisy and 14% had skin irritations caused by the ear mold. Walden and Walden

(2005) compared unilateral and bilateral aided speech recognition in background noise. Results suggested that bilateral amplification may not always be beneficial in every daily listening environment when background noise is present, in particular among older patients, who tended to have better performance with unilateral amplification. Similar results have been reported by Henkin et al (2007), Freyaldenhoven et al (2006), Hickson (2006), and Holmes (2003). This indicates that some subjects may not take advantage of two aids in certain situations or at all, and they could have been fitted with one aid, as well.

Level of signal processing

For the associations between the level of hearing aid signal processing and hearing aid outcome, equivocal results were found in our study. Descriptive statistics indicated that users of complex devices used their aids more frequently when measured in hours per day, but not in days per week. They were also more likely to be very satisfied and able to handle their aids very well. Logistic regression analyses taking into account potentially confounding factors yielded a somewhat different pattern of results. While the owners of simple aids were at a higher risk of non-regular use, they were more likely to be satisfied with their aids compared to those with more complex devices. In contrast to our hypothesis that automatic control features could contribute to easier management, the ability to handle the aid was unrelated to the level of signal processing. This outcome pattern is difficult to interpret. Although advanced technology seems to increase the duration of use, the lower satisfaction with complex devices could indicate the limitations of hearing aid technology that cannot fully compensate for the hearing loss. It might also indicate that owners of complex devices had higher and possibly unrealistic expectations than those of simple devices.

Studies with a cross-over design reported subjective preference of hearing aids with more advanced technology after subjects had tried both hearing aids with simple and complex signal processing for some time (Larson et al, 2000; Newman and Sandridge, 1998; Wood and Lutman, 2004). Boysman et al. (2009) classified hearing aids into three categories (basic

69%, advanced 17%, high-end 14%). No significant differences in hearing aid use were found among the three groups, but for the outcome measure of residual handicap the high-end hearing aid users scored more favourably than those with basic hearing aids.

Jerram and Purdy (2001) investigated the influence of technology, demographic factors and prefitting expectations on three hearing aid outcome measures: perceived hearing aid benefit, overall satisfaction and daily hours of use. Hearing aid technology categories were wide dynamic range compression, other types of input or output compression, peak clipping, multiple channels, multiple memories, and multiple microphones. Hearing aid use was significantly affected by prefitting expectations and acceptance of hearing loss, but not by hearing aid technology. Multiple-memory and multiple-microphone hearing aids yielded higher satisfaction ratings. These results are in contrast with the findings from our study, where user rates were significantly affected by hearing aid technology favouring devices with advanced signal processing, whereas satisfaction rates were higher for devices with simpler technology. The different results may be related to methodological differences. The study of Jerram and Purdy (2001) had a prospective design with subjects at their initial hearing aid evaluation responding to a set of questionnaires approximately 10 weeks after their final hearing aid follow-up appointment. At that stage, long-term acceptance and judgment of the aid are most likely not yet established. In our cross-sectional study, the duration of hearing aid use varied from less than 1 year to 65 years. Sixty-five percent of the respondents had used their device for at least 2 years.

Price and age of the hearing aid may indirectly provide information on the complexity of signal processing. Expensive and recently purchased instruments are most likely equipped with more sophisticated technology than less expensive and older instruments. In a large epidemiological study, Parving (2003) compared hearing aid outcome for low- and high-cost digital signal processing hearing aids that had been dispensed between 1999 and 2001 in Denmark. No significant differences were found for satisfaction and regular use, but a higher proportion of subjects was able to manage the high-cost instruments. However, this difference was ascribed to the younger age of the subjects fitted with the high-cost hearing aids. In one of the MarkeTrak surveys carried out by Kochkin (2003), the relationship between price, hearing aid type and satisfaction was analysed in a subgroup of hearing aids less than 3 years of age. The overall satisfaction was 58% for non-programmable, 72% for programmable aids with omnidirectional microphone, and 81% for programmable hearing instruments including directional microphones, but there was no correlation between price and satisfaction (r=0.02). Kochkin also explored customer satisfaction as a function of age of the hearing instrument. Satisfaction ratings increased steadily from 51% for hearing aids older than 10 years to 78% for 1-year-old aids (Kochkin, 2005). In our study we found significantly higher satisfaction for hearing aids of less than 1 year of age compared to hearing aids between 1 and 5 years of age, indicating a preference for the most recent instruments. However, this is in contrast with the higher satisfaction rate for simple devices found in our study.

In conclusion, the results of the various studies regarding the relationships between hearing aid outcome measures and hearing aid technology are inconsistent and there is no clear evidence for a superiority of high-tech instruments. However, studies with a cross-over design, where patients wore different types of hearing aids for some time allowing them a direct comparison, consistently report preference for devices with more complex signal processing features.

Degree of hearing loss

In the current study, degree of hearing loss was found to be a strong determinant of regular hearing aid use. This finding is in line with the results of other studies (Cox et al, 2003; Davis et al, 2007; Popelka et al, 1998). In contrast, there was no relationship between hearing loss and satisfaction. The lack of a significant relationship between hearing loss and satisfaction has been reported by various studies (Bentler et al, 1993; Dillon et al, 1997; Gatehouse, 1994; Hickson et al, 1999; Jerram and Purdy, 2001; Norman et al, 1994). It appears that use and satisfaction represent different dimensions of hearing aid outcome. Other studies have reported correlation coefficients varying between -.24 to .66 (Wong et al, 2003). The correlation between hearing aid use (days per week) and satisfaction in this study was relatively low (r=0.25; additional analysis, not yet reported). Thus, a person may use an aid during the whole day, but may not be satisfied with it. Likewise, another person may be satisfied with the aid, but use it only occasionally. In our study, more than 60% of the occasional users indicated that they were satisfied with their aid (Bertoli et al, 2009).

An interesting result was that hearing aid users with moderate and severe hearing loss had significantly more difficulty handling their aids well than those with mild hearing loss, whereas neither type of fitting nor complexity of the devices affected management. As hearing loss is known to increase with increasing age, this finding could, at least in part, be attributed to the higher age of those with severe hearing loss. However, the results of the logistic regression analysis do not support this view, as there was no association between management and age of the hearing aid users. The fact that technology factors were unrelated to management could indicate that devices can be managed well irrespective of the complexity of signal processing features, when careful and adequate counselling is provided. On the other hand, it points again to the limitations of technology. Hearing aids, even those with the most advanced signal processing features, cannot restore normal hearing completely. This lack becomes more evident as hearing loss increases and may be perceived by the hearing-impaired person as difficulty with the management of the aid.

Hearing aid outcome measures

Logistic regression analyses revealed various factors that affected hearing aid outcome significantly. The strongest associations were seen between the three outcome variables of use, satisfaction and management. Strong correlations between use, satisfaction and management have been reported in many previous studies (for a review, see Wong et al, 2003) and may be explained by the fact that they represent closely related - though different - aspects of hearing aid outcome.

In none of the studies with more than one outcome measure reviewed by us, significant differences between the groups were identified for all measures considered. This emphasizes that more than one parameter should be used for a comprehensive evaluation of hearing aid outcome, because use, satisfaction, management and benefit represent different aspects of overall hearing aid outcome. The lack of converging results for use, satisfaction and management in our study supports this view. While usage may be considered a more objective, quantitative criterion, satisfaction and management may represent more emotional or subjective dimensions. In particular, satisfaction could be determined by factors such as personality, prefitting expectations, acceptance of hearing loss and perceived handicap. It should, however, also be noted that the most sensitive outcome parameter appeared to be hearing aid use (measured in terms of days per week), as significant associations were found for all three independent variables (fitting type, level of signal processing, hearing loss).

The Swiss model of hearing aid provision

The differences in usage between the bilateral and unilateral group and between users of complex and simple devices in our study were relatively small. Compared to the results of studies from other countries, use, satisfaction and management rates for unilaterally fitted persons and owners of simple devices must be still considered excellent (Dillon et al, 1999; Lupsakko and Kautiainen, 2005; Parving, 2003; Smeeth et al, 2002; Smith et al, 2005; Stark and Hickson, 2004; Stephens et al, 2001; Stock et al, 1997; Uriarte et al, 2005; Vuorialho et al, 2006). It appears that the Swiss hearing aid dispensing model with a careful comparative fitting and continued counselling after the initial fitting has contributed substantially to the high regular-use, satisfaction and management rates regardless of the signal processing complexity and fitting type. The criteria used to determine candidacy for a hearing aid, which are not limited to the degree of hearing loss but include non-audiometric factors such as the handicap resulting from hearing loss, may also have contributed to the results. This is supported by the high percentage of 88.5% of the bilaterally fitted persons who wore both aids regularly. Corresponding percentages reported from other studies ranged between 68% and 80% (Dillon et al, 1999; Kobler et al, 2001). In addition, 91% of our sample were able to manage their aid(s) very well or rather well compared to Parving (2003), who reported good management rates for analog and digital instruments of 80% and 82%, respectively. Dillon et al. (1999) indicated that 48% had a problem with handling. In view of the high percentages of regular use, satisfaction and good management, the relatively small differences between the groups could also be the result of a ceiling effect, i.e., as hearing aid users already score close to the maximum values, a further improvement in hearing aid provision can no longer be captured.

Our data also clearly show that the Swiss hearing aid dispensing model with different reimbursement criteria for employed and retired hearing aid candidates results in a significantly higher proportion of bilateral fittings (80-91%) for those aged between 18 and 69 years than for those ≥70 years (67-33%). Boysman et al. (2009), with data from several Dutch audiological centers considered to be representative of the fitting practices in the Netherlands, reported a proportion of approximately 60% across the whole age range from 15 to >95 years, which corresponds to the overall proportion of bilateral fittings of 60.5% for our whole study population including subjects with asymmetric hearing loss (Bertoli et al, 2009). It must therefore be questioned whether the different reimbursement criteria in Switzerland favour hearing aid provision among the young and employed at the expense of the elderly and retired. This is supported by the higher proportion of bilateral fittings in persons with mild hearing loss compared to moderate and severe hearing loss (73% vs. 69% and 66%, respectively) in our study, whereas in the Dutch survey bilateral fittings were more frequent in moderate to severe hearing loss (PTA > 35 dB: 48-73%) compared to mild hearing loss (PTA ≤ 35 dB: 4-29%).

Acknowledgements

We wish to thank Christian Schindler for assistance with statistical analyses.

This work was supported by grants from Amplifon AG Schweiz, Charles Holland Foundation Milano, Lotteriefonds Baselland, Eidgenössische Finanzkontrolle Bern.

The study was conducted independent of the funding agencies. Amplifon supplied addresses of their customers and provided data on hearing loss and hearing aids for respondents. Amplifon did not participate in data collection, data analysis, or interpretation of results. The Swiss Federal Audit Office (Eidgenössische Finanzkontrolle) received a report of the results for an evaluation of the provision of hearing aids supported by the social insurance system in Switzerland.

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Tables

Table 1: Hearing aid categories

Category	Features
1	Linear signal processing
2	Nonlinear signal processing, omnidirectional or fixed directional microphone, no speech recognition, no noise suppression
3	Nonlinear signal processing, omnidirectional or fixed directional microphone, one-channel speech recognition or noise suppression, feedback suppression
4	Nonlinear at least 3-channel signal processing, omnidirectional or fixed directional microphone, multi-channel speech recognition and noise suppression, adaptive feedback suppression
5	Nonlinear at least 3-channel signal processing, adaptive directional microphone, multi-channel speech recognition and noise suppression, adaptive feedback suppression
6	Nonlinear signal processing, adaptive multi-channel directional microphone, multi-channel speech recognition and noise suppression, active feedback suppression

Table 2: Demographic data by type of fitting and level of hearing aid signal processing

	Type of fitting (n=6027)			Level of signal processing (n=5973)		
	Bilateral (n=4182)	Unilateral (n=1845)	p-value	Complex (n=3720)	Simple (n=2253)	p-value
	No. (row%)	No. (row%)		No. (row%)	No. (row%)	
Age groups (years)						
18-29	12 (80.0)	3 (20.0)	<.0001 [a]	7 (46.7)	8 (53.3)	.6866 [a]
30-39	44 (88.0)	6 (12.0)		29 (58.0)	21 (42.0)	
40-49	125 (91.24)	12 (8.8)		87 (64.0)	49 (36.0)	
50-59	396 (90.0)	44 (10.0)		257 (59.8)	173 (40.2)	
60-69	1077 (87.0)	161 (13.0)		768 (62.5)	460 (37.5)	
70-79	1300 (67.8)	617 (32.2)		1212 (63.9)	686 (36.1)	
80-89	1070 (57.2)	800 (42.8)		1151 (61.9)	708 (38.1)	
90-99	156 (44.1)	198 (55.9)		205 (58.1)	148 (41.9)	
≥100	2 (33.3)	4 (66.7)		4 (100.0)	0 (0.00)	
Gender						
Men	2639 (72.2)	1014 (27.8)	<.0001 [b]	2274 (62.8)	1346 (37.2)	.288 [b]
Women	1543 (65.0)	831 (35.0)		1446 (61.4)	907 (38.6)	

[a] Wilcoxon rank sum test
[b] Chi-square test

Table 3: Percent hearing loss using the CPT-AMA criteria (see text for explanation of calculation) as by type of fitting and level of hearing aid signal processing

	Amplification type (n=6027)			Level of signal processing (n=5974)		
	Bilateral (n=4182)	Unilateral (n=1845)	p-value	Complex (n=3721)	Simple (n=2253)	p-value
	No. (row%)	No. (row%)		No. (row%)	No. (row%)	
Hearing loss of better ear (CPT-AMA)						
Mild (≤40%)	1387 (73.1)	510 (26.9)	<.0001 [a]	1230 (65.2)	657 (34.8)	.0009 [a]
Moderate (41-60%)	1588 (69.3)	703 (30.7)		1406 (61.8)	870 (38.2)	
Severe (>60%)	1207 (65.6)	632 (34.3)		1085 (59.9)	726 (40.1)	

[a] Wilcoxon rank sum test

Table 4: Age of current aid, overall duration of hearing aid use and hearing aid category by type of fitting and level of hearing aid signal processing

	Type of fitting (n=6027)			Level of signal processing (n=5974)		
	Bilateral (n=4182)	**Unilateral (n=1845)**	**p-value**	**Complex (n=3721)**	**Simple (n=2253)**	**p-value**
	No. (%)	**No. (%)**		**No. (%)**	**No. (%)**	
When did you purchase the most current hearing aid?						
<1 year	1030 (24.6)	334 (18.1)		988 (26.6)	358 (15.9)	
1-2 years	1365 (32.6)	621 (33.7)		1271 (34.2)	704 (31.3)	
>2 years	1086 (26.0)	597 (32.4)	<.0001 [a]	928 (24.9)	747 (33.2)	<.0001 [a]
>5 years	661 (15.8)	271 (14.7)		496 (13.3)	421 (18.7)	
No answer	40 (1.0)	22 (1.2)		38 (1.0)	23 (1.0)	
When was your first hearing aid purchased?						
0-1 year	1201 (28.7)	445 (24.2)		1125 (30.2)	515 (22.9)	
2-5 years	1070 (25.6)	642 (34.8)		987 (26.5)	714 (31.7)	
6-10 years	801 (19.2)	283 (15.3)	.048 [a]	704 (18.9)	370 (16.4)	<.0001 [a]
>10 years	817 (19.5)	276 (15.0)		629 (16.9)	440 (19.5)	
No answer	293 (7.0)	198 (10.7)		276 (7.4)	214 (9.5)	
Hearing aid category						
Category 1	80 (1.9)	57 (3.1)				
Category 2	307 (7.3)	239 (13.0)				
Category 3	1035 (24.8)	535 (29.0)				
Category 4	656 (15.7)	220 (11.9)	<.0001 [a]			
Category 5	1930 (46.2)	751 (40.7)				
Category 6	136 (3.3)	28 (1.5)				
No answer	38 (0.9)	15 (0.8)				
Simple (Categories 1-3)	1422 (34.0)	831 (45.0)				
Complex (Categories 4-6)	2722 (65.1)	1002 (54.1)	<.0001 [b]			

[a] Wilcoxon rank sum test
[b] Chi-square test

Table 5: Use, satisfaction and management by type of fitting

(n=6027)	Bilateral (n=4182)	Unilateral (n=1845)	p-value
	No. (%)	No. (%)	
Do you use your hearing aid (use in days per week):			
Every day	2509 (60.0)	1099 (59.6)	.0580 [a]
Most days (5-6days per week)	864 (16.4)	232 (12.6)	
Some days (1-4 days per week)	565 (13.5)	242 (13.1)	
Only occasionally	380 (9.1)	249 (13.5)	
Not at all	31 (0.7)	18 (1.0)	
No answer	13 (0.3)	5 (0.3)	
How many hours a day do you think you use the hearing aid on an average day (use in hours per day)			
More than 8 hours	2240 (53.6)	819 (44.4)	<.0001 [a]
Between 4 and 8 hours	1103 (26.4)	461 (25.0)	
Between 1 and 4 hours	695 (16.6)	460 (24.9)	
Less than 1 hour	105 (2.5)	69 (3.7)	
No answer	39 (0.9)	36 (2.0)	
Are you satisfied with your hearing aid?			
Very satisfied	1482 (35.4)	551 (29.9)	<.0001 [a]
Rather satisfied	2166 (51.8)	1002 (54.3)	
Rather dissatisfied	418 (10.0)	238 (13.0)	
Very dissatisfied	84 (2.0)	37 (2.0)	
No answer	32 (0.8)	17 (0.9)	
Can you manage your hearing aid?			
Very well	2140 (51.2)	775 (42.01)	<.0001 [a]
Rather well	1731 (41.4)	866 (46.9)	
Rather bad	241 (5.8)	160 (8.7)	
Very bad	37 (0.9)	23 (1.3)	
No answer	33 (0.8)	21 (1.1)	

[a] Wilcoxon rank sum test

Table 6: Use, satisfaction and management by level of hearing aid signal processing

(n=5974)	Complex (n=3721)	Simple (n=2253)	p-value
	No. (%)	No. (%)	
Do you use your hearing aid (use in days per week):			
Every day	2231 (60.0)	1341 (59.5)	.1147 [a]
Most days (5-6days per week)	616 (16.6)	294 (13.1)	
Some days (1-4 days per week)	486 (13.1)	315 (14.0)	
Only occasionally	356 (9.6)	270 (12.0)	
Not at all	23 (0.6)	25 (1.1)	
No answer	9 (0.3)	8 (0.4)	
How many hours a day do you think you use the hearing aid on an average day (use in hours per day)			
More than 8 hours	1931 (51.9)	1093 (48.5)	.0108 [a]
Between 4 and 8 hours	967 (26.0)	587 (26.1)	
Between 1 and 4 hours	676 (18.2)	475 (21.1)	
Less than 1 hour	111 (3.0)	61 (2.7)	
No answer	36 (1.0)	37 (1.6)	
Are you satisfied with your hearing aid?			
Very satisfied	1292 (34.7)	721 (32.0)	.0397 [a]
Rather satisfied	1931 (51.9)	1217 (55.0)	
Rather dissatisfied	403 (10.8)	243 (10.8)	
Very dissatisfied	65 (1.8)	54 (2.4)	
No answer	30 (0.8)	18 (0.8)	
Can you manage your hearing aid?			
Very well	1881 (50.6)	1008 (44.7)	<.0001 [a]
Rather well	1546 (41.6)	1030 (45.7)	
Rather bad	229 (6.2)	168 (7.5)	
Very bad	32 (0.9)	26 (1.2)	
No answer	33 (0.9)	21 (0.9)	

[a] Wilcoxon rank sum test

Table 7: Use, satisfaction and management across different levels of hearing loss

(n=6027)	Mild (n=1897)	Moderate (n=2291)	Severe (n=1839)	p-value
	No. (%)	No. (%)	No. (%)	
Do you use your hearing aid (use in days per week):				
Every day	768 (40.5)	1317 (57.5)	1523 (82.8)	<.0001 [a]
Most days (5-6days per week)	380 (20.0)	381 (16.6)	155 (8.4)	
Some days (1-4 days per week)	399 (21.0)	320 (14.0)	88 (4.8)	
Only occasionally	319 (16.8)	245 (10.7)	65 (3.5)	
Not at all	25 (1.3)	19 (0.8)	5 (0.3)	
No answer	6 (0.3)	9 (0.4)	3 (0.2)	
How many hours a day do you think you use the hearing aid on an average day (use in hours per day)				
More than 8 hours	715 (37.7)	1087 (47.5)	1257 (68.4)	<.0001 [a]
Between 4 and 8 hours	577 (30.4)	628 (27.4)	359 (19.5)	
Between 1 and 4 hours	483 (25.5)	479 (20.9)	193 (10.5)	
Less than 1 hour	92 (4.9)	66 (2.9)	16 (0.9)	
No answer	30 (1.6)	31 (1.4)	14 (0.8)	
Are you satisfied with your hearing aid?				
Very satisfied	694 (36.6)	727 (31.7)	612 (33.3)	.1117 [a]
Rather satisfied	950 (50.1)	1230 (53.7)	988 (53.7)	
Rather dissatisfied	200 (10.5)	261 (11.4)	195 (10.6)	
Very dissatisfied	39 (2.1)	51 (2.2)	31 (1.7)	
No answer	14 (0.7)	22 (1.0)	13 (0.7)	
Can you manage your hearing aid?				
Very well	985 (51.9)	1080 (47.1)	850 (46.2)	.0014 [a]
Rather well	769 (40.5)	992 (43.3)	836 (45.5)	
Rather bad	110 (5.8)	175 (7.6)	116 (6.3)	
Very bad	20 (1.1)	22 (1.0)	18 (1.0)	
No answer	13 (0.7)	22 (1.0)	19 (1.0)	

[a] Spearman's rank correlation

Table 8: Reasons for non-use of the hearing aids by type of fitting and level of hearing aid signal processing, as reported by those subjects who used their aids only occasionally or never

	Type of fitting (n=678)			**Level of hearing aid signal processing (n=674)**		
	Bilateral (n=411)	**Unilateral (n=267)**	**p-value[a]**	**Complex (n=379)**	**Simple (n=295)**	**p-value[a]**
	No. (%)	**No. (%)**		**No. (%)**	**No. (%)**	
Noisy situations are disturbing	231 (56.2)	124 (46.4)	0.013	196 (51.7)	155 (52.5)	.157
Other reasons	127 (30.9)	70 (26.2)	0.189	109 (28.4)	88 (29.8)	.419
No need	107 (26.0)	67 (25.1)	0.784	106 (28.0)	67 (22.7)	.301
Unpleasant side effects (e.g., rashes, itching, pain, builds up wax)	96 (23.4)	41 (15.4)	0.011	73 (19.3)	62 (21.0)	.282
No/poor benefit	95 (23.1)	75 (28.1)	0.144	102 (26.9)	68 (23.1)	.264
Poor sound quality	58 (14.1)	31 (11.6)	0.346	54 (14.3)	35 (11.9)	.488
Poor fit and comfort	50 (12.2)	16 (6.0)	0.008	38 (10.0)	27 (9.2)	.546
Difficulties with management	28 (6.8)	29 (10.9)	0.063	26 (6.9)	31 (10.5)	.198

[a] Chi-square test

Table 9: Logistic regression model for non-regular use

Non-regular use (n=5354)	Odds Ratio	95% confidence interval	p-value
Age			
≤ 64 years	1 [a]		
65-74 years	1.23	0.93-1.63	0.140
75-84 years	1.05	0.79-1.40	0.718
≥ 85 years	1.13	0.79-1.62	0.491
Gender			
Men	1 [a]		
Women	0.61	0.49-0.75	<0.0001
Total duration of hearing aid use			
0-1 year	1 [a]		
2-5 years	1.05	0.79-1.41	0.715
6-10 years	0.38	0.26-0.57	<0.0001
>10 years	0.55	0.36-0.83	0.005
Age of current hearing aid			
<1 year	1 [a]		
1-2 years	1.02	0.78-1.34	0.874
>2 years	1.15	0.81-1.63	0.427
>5 years	1.07	0.67-1.70	0.790
Bilateral/unilateral fitting			
Bilateral	1		
Unilateral	1.38	1.12-1.71	0.003
Satisfaction			
Very satisfied	1 [a]		
Rather satisfied	1.99	1.46-2.70	<0.0001
Rather dissatisfied	4.00	2.71-5.89	<0.0001
Very dissatisfied	4.94	2.57-9.50	<0.0001
Management			
Very good	1 [a]		
Rather good	1.75	1.36-2.26	<0.0001
Rather bad	6.07	4.20-8.79	<0.0001
Very bad	13.59	6.13-30.12	<0.0001
Hearing loss better ear (CPT-AMA)			
Mild (≤ 40%)	1 [a]		
Moderate (41-60%)	0.50	0.41-0.63	<0.0001
Severe (>60%)	0.19	0.14-0.28	<0.0001
Hearing aid category			
Complex	1 [a]		
Simple	1.25	1.03-1.52	0.023

[a] Reference category for the variable. Odds ratios of the other categories indicate the change in risk compared to the reference category: Odds ratios <1 indicate a decrease in risk, odds ratios >1 an increase in risk.

The overall model evaluation using the likelihood ratio yielded a $chi^2(20)$ of 767.48 and a p-value of p<.0001 indicating that the logistic model captured important factors.

The goodness of fit statistics (Hosmer-Lemeshow chi^2 test) provided a $chi^2(8)$ of 11.24 and a p-value of 0.1883 indicating a good fit of the logistic model.

The adjusted prevalences of irregular use in bilateral users were 5.9% (95% CI 5.1%-6.7%) compared to 7.9% (95% CI 6.7%-9.5%) in unilateral users and 5.9% (95% CI 5.1%-6.9%) in owners of complex devices compared to 7.3% (6.2%-8.6%) in those with simple devices.

Table 10: Logistic regression model for dissatisfaction

Dissatisfaction (n=5354)	Odds Ratio	95% confidence interval	p-value
Age			
≤ 64 years	1 [a]		
65-74 years	1.19	0.88-1.62	0.259
75-84 years	1.09	0.81-1.48	0.569
≥ 85 years	1.07	0.75-1.54	0.705
Gender			
Men	1 [a]		
Women	0.89	0.72-1.10	0.296
Total duration of hearing aid use			
0-1 year	1 [a]		
2-5 years	1.49	1.08-2.05	0.015
6-10 years	1.41	0.99-2.00	0.056
>10 years	1.40	0.96-2.05	0.078
Age of current hearing aid			
<1 year	1 [a]		
1-2 years	1.36	1.00-1.84	0.046
>2 years	1.45	1.01-2.07	0.041
>5 years	1.37	0.92-2.03	0.117
Bilateral/unilateral fitting			
Bilateral	1 [a]		
Unilateral	1.01	0.80-1.26	0.956
Management			
Very good	1 [a]		
Rather good	3.16	2.47-4.03	<0.0001
Rather bad	56.09	40.38-77.93	<0.0001
Very bad	127.29	47.43-341.57	<0.0001
Hearing aid use			
Every day	1 [a]		
Most days (at least 5 days per week)	1.09	0.80-1.48	0.588
Some days (1-4 days per week)	1.30	0.96-1.76	0.084
Only occasionally	2.33	1.73-3.13	<0.0001
Not at all	56.64	6.45-496.92	<0.0001
Hearing loss better ear (CPT-AMA)			
Mild (≤ 40%)	1 [a]		
Moderate (41-60%)	1.05	0.82-1.36	0.667
Severe (>60%)	1.01	0.73-1.39	0.960
Hearing aid category			
Complex	1 [a]		
Simple	0.80	0.65-0.98	0.035

[a] Reference category for the variable. Odds ratios of the other categories indicate the change in risk compared to the reference category: Odds ratios <1 indicate a decrease in risk, odds ratios >1 an increase in risk.

The overall model evaluation using the likelihood ratio yielded a $chi^2(21)$ of 1205.79 and a p-value of p <.0001 indicating that the logistic model captured important factors..

The goodness of fit statistics (Hosmer-Lemeshow chi^2 test) provided a $chi^2(8)$ of 8.09 and a p-value of 0.4249 indicating a good fit of the logistic model.

The adjusted prevalences of dissatisfation were 8.0% (95% CI 7.0%-9.1%) in bilateral users and 8.0% (95% CI 6.7%-9.6%) in unilateral users, and 8.6% (95% CI 7.6%-9.8%) in owners of complex devices compared to 7.0% (95% CI 5.9%-8.3%) in those with simple devices.

Table 11: Logistic regression model for difficulty with management

Difficulty with management (n=5354)	Odds Ratio	95% confidence interval	p-value
Age			
≤ 64 years	1 [a]		
65-74 years	0.74	0.49-1.11	0.148
75-84 years	0.90	0.61-1.34	0.618
≥ 85 years	1.04	0.66-1.65	0.863
Gender			
Men	1 [a]		
Women	1.02	0.78-1.35	0.860
Total duration of hearing aid use			
0-1 year	1 [a]		
2-5 years	1.00	0.66-1.50	0.998
6-10 years	0.94	0.60-1.49	0.809
>10 years	0.83	0.50-1.36	0.454
Age of current hearing aid			
<1 year	1 [a]		
1-2 years	1.25	0.84-1.85	0.271
>2 years	1.21	0.76-1.92	0.408
>5 years	1.17	0.69-1.97	0.564
Bilateral/unilateral fitting			
Bilateral	1 [a]		
Unilateral	1.23	0.92-1.64	0.161
Satisfaction			
Very satisfied	1		
Rather satisfied	25.04	6.15-102.00	<0.0001
Rather dissatisfied	476.43	117.42-1933.14	<0.0001
Very dissatisfied	571.82	132.47-2468.35	<0.0001
Hearing aid use			
Every day	1 [a]		
Most days (at least 5 days per week)	1.01	0.64-1.58	0.973
Some days (1-4 days per week)	2.03	1.37-3.00	<0.0001
Only occasionally	5.21	3.64-7.43	<0.0001
Not at all	15.95	5.31-47.85	<0.0001
Hearing loss better ear (CPT-AMA)			
Mild (≤ 40%)	1 [a]		
Moderate (41-60%)	1.69	1.21-2.38	0.002
Severe (>60%)	2.37	1.54-3.64	<0.0001
Hearing aid category			
Complex	1 [a]		
Simple	1.19	0.92-1.56	0.189

[a] Reference category for the variable. Odds ratios of the other categories indicate the change in risk compared to the reference category: Odds ratios <1 indicate a decrease in risk, odds ratios >1 an increase in risk.

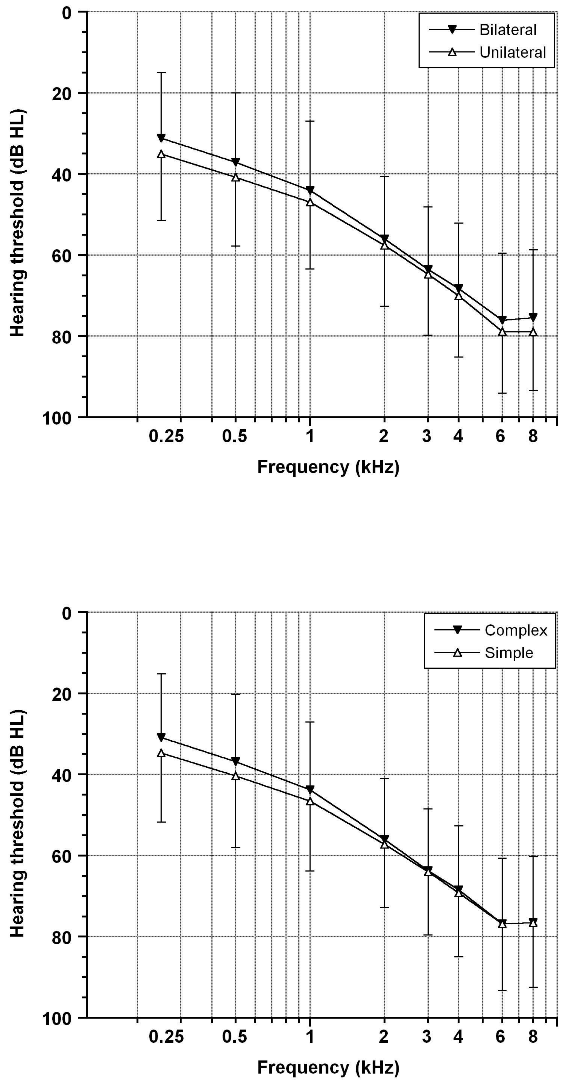
The overall model evaluation using the likelihood ratio yielded a $chi^2(21)$ of 1210.53 and a p-value of p<.0001 indicating that the logistic model captured important factors..

The goodness of fit statistics (Hosmer-Lemeshow chi^2 test) provided a $chi^2(8)$ of 3.09 and a p-value of 0.9283 indicating a good fit of the logistic model.

The adjusted prevalences of difficulty with management in bilateral users were 1.2% (95% CI 0.8%-2.0%) compared to 1.5% (95% CI 0.9%-2.5%) in unilateral users and 1.2% (95% CI 0.7%-2.0%) in owners of complex devices compared to 1.5% (95% CI 0.9%-2.5%) in those with simple devices.

Figure legends

Figure 1: Composite mean hearing thresholds (± 1 standard deviation) of right and left ears as a function of fitting type (upper panel) and signal processing level (lower panel)



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